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By

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CONTRIBUTION TO THE PROBLEM OF THE EFFECT OF THE ATMOSPHERE ON THE RADIATION OF AN ARC DISCHARGE (2nd Installment)

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An analysis of the causes which bring about a change in the character of the spectrum in a weak-current arc with a change in the atmosphere, warrants one's assuming that the redistribution of the intensity in the spectrum of atoms coming from electrodes when there is a change from air to inert gas, is produced by the change in the concentration of these atoms and the temperature of the arc discharge T(r). The difference in T(r) with the substitution of gas is connected with the change in concentration of easily ionized atoms coming from the electrodes, of the effective scattering of electrons by the arc gas, and in the case of a molecular gas, of its dissociation (see report I [1]).

This project is undertaken for the purpose of making a confrontation of the radiation, the entering of the vapors of the electrodes (of the wear of the electrodes during a determined time of the burning of the discharge) and of the external form of the arc discharges between the metallic and the carbon electrodes in an atmosphere of argon, air, and nitrogen, under identical pressure, and nitrogen and air with lowered pressure ($V_{jAr} = 15.756$ ev, $V_{jN_2} = 15.58$ ev). It has been proposed that in an arc discharge between metallic electrodes in Ar and in nitrogen with lowered pressure, corresponding to the equalizing of the entering of vapors into Ar and N_2 and of effective sections of scattering of electrons by an arc gas it is possible to obtain spectra close as to the intensity and character of the radiation. In a discharge between carbon electrodes in the air and nitrogen, the temperatures attributable to $V_{jC} > V_{jM}$ are sufficient for the development of

the processes of dissociation, due to which the assurance of a close inflow of vapors of the electrodes may prove to be insufficient for obtaining a similarity of spectra in N_2 and Ar.

For the investigation there was used the vacuum arc described by us earlier [2]. Before filling with Ar or N_2 the vacuum arc was pumped out to a pressure $\sim 10^{-2}$ mm Hg column, and afterwards was flushed with Ar or N_2, respectively. In the work pure Ar was used containing an insignificant admixture of nitrogen (0.2%) and oxygen (0.05%). The spectra were obtained with the aid of the spectrographs ISP-28 and ISP-51 and the camera UF-84. The arc discharges between the metallic and carbon electrodes were researched at a current strength of 9 amp. The distance between the electrodes was about 4 mm. For stabilization of the arc discharge the cathode was sharpened to a cone.

1. Discharge between Metallic Electrodes

In Fig. 1 there are presented the spectra of an arc discharge between iron electrodes in the air with a pressure of 60 cm Hg column, in nitrogen with a pressure of 60, 20, and 2 cm Hg column, and in argon with a pressure of 60 cm Hg column. Let us note that in all the listed spectra there is absent the radiation of the atmosphere itself in which the discharge takes place, and in the spectrum there is only present radiation of the vapors of iron. An exception is constituted by the spectrum of the arc between iron electrodes in N_2 with a pressure of 2 cm Hg column, in which there are present 2 borders of the band NH corresponding to $\Delta v = 0$, 3360 and 3370 Å and a super imposed borders of the band N_2 Å ($\Delta v = 0$). These bands prove to be the brightest ones of the system of bands of NH and N_2. The identification of the borders of the bands was done on the basis of Peirce and Haydon's monograph [3].

In the confrontation of the spectra in Fig. 1 we see the following. A replacing of the air by nitrogen with 60 cm pressure already brings about a change in the character of the spectrum--the spectrum becomes more sparklike. A still more sparklike character is displayed by the spectrum of Fe in N_2 at 20 cm Hg column. The spectra of Fe in Ar at 60 cm and in nitrogen at 2 cm Hg column are very similar to each other and there is sharply expressed the sparklike character as compared with the spectra in air and nitrogen at 60 cm Hg column. For illustration of the character of the spectrum above there are noted some groupings and separate lines of Fe II; below by dots there are noted some lines of Fe I located in the short-wave part of the spectrum. As the result of a careful analysis of the spectra of Fe in Ar and N_2 with a pressure of 60 cm and in N_2 with a pressure of 2 cm it has been established that there takes place not only an external convergence of the spectra at 60 cm in N_2 at 2 cm, but also the intensities of the individual spectral lines in the compared spectra were close to each other.

Particular attention was given to the evaluation of the relationship of the ionic lines of Fe in the spectrum of the arc in Ar in which one could see reflected the selective amplification through impacts of the 2nd kind with excited atoms of Ar, and also with ions of Ar in fulfilling the resonance conditions $(V_j + E_a)_{Fe} \rightarrow E_{aAr}$ or V_{jAr}. Among the lines of Fe in the region 3,303—2,260 Å with energy of excitation E_a in the interval 12.71—13.76 ev there are lines for which $(V_j + E_a)_{Fe}$ find themselves in good resonance with E_a of the excited levels of Ar located in the interval 12.9—13.47 ev or close to V_{jAr}. It has been established that in the arc of Fe electrodes in argon there is no slective amplification of the ion lines of Fe resulting from impacts of the second kind with atoms or ions of Ar.

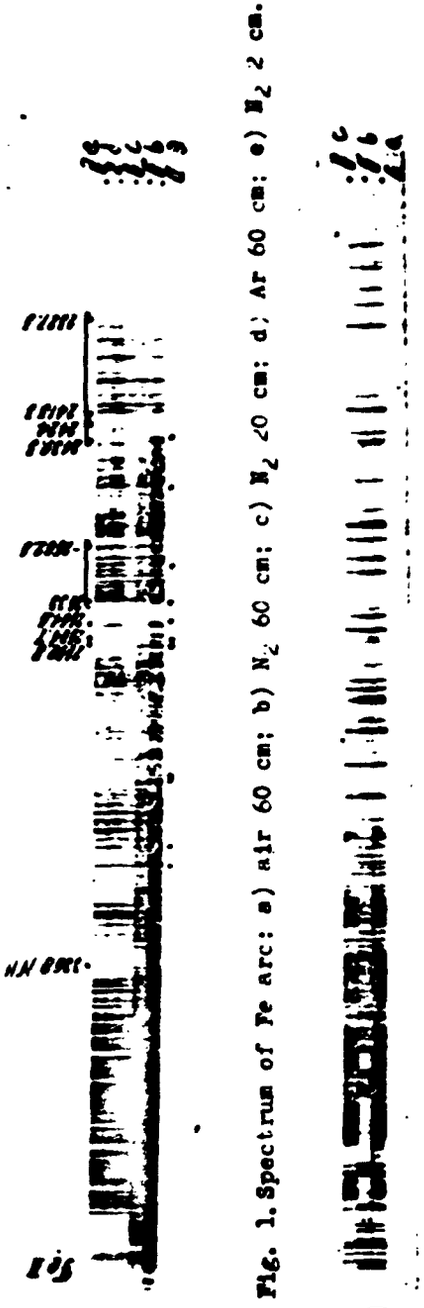

Fig. 1. Spectrum of Fe arc: a) air 60 cm; b) N_2 60 cm; c) N_2 20 cm; d) Ar 60 cm; e) N_2 2 cm.

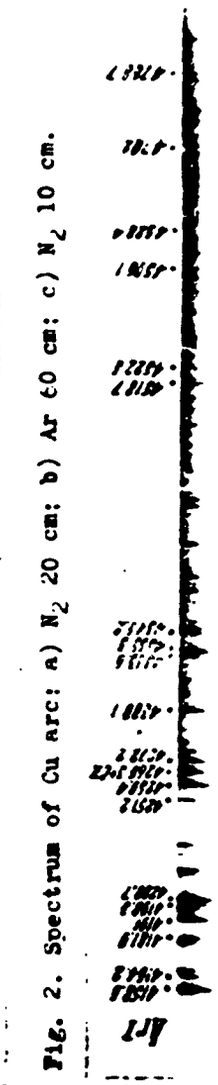

Fig. 2. Spectrum of Cu arc: a) N_2 20 cm; b) Ar 60 cm; c) N_2 10 cm.

The confrontation of a large number of spectra of arcs between Fe electrodes in Ar at 60 cm and in N_2 at 2 cm shows that the general intensity and character of these spectra changes from spectrum to spectrum, whereas the spectra in N_2 at 2 cm can be brighter and weaker as compared with the spectra in Ar at 60 cm. The same can be said also about the character of these spectra--in individual instances there occurs a more sparklike character of the spectrum in the arc in N_2 at 2 cm. In others, on the contrary, it is more are like than in the spectrum of the arc in Ar at 60 cm. Spectra in Ar at 60 cm and in N_2 that are close in intensity and character were obtained by

Fig. 3. Cathode layer.

us not only at 2 cm in N_2, but in a certain not very large interval around 2 cm, approximately from 0.6 to 3--4 cm Hg column. This points to the great significance for the assuring of the convergence of spectra of the passing

of vapors of Fe from the electrodes into the space between the electrodes, which always fluctuates.

For confrontation of the changes in the character of the spectra with a change of atmosphere and change in the concentration of atoms passing from the electrodes in the discharge a verification was made of the change in the weight of the electrodes during a certain amount of time of the existence of the discharge. In Table 1 there are presented the results of the evaluation of the losses of the electrodes, separately for anode and cathode, expressed in milligrams per minute during the burning of the arc in ar, N_2, and air. The data presented represent the average values from ten determinations. In the table there are shown the differences of the potentials in volts on the electrodes of the arc.

Table 1

Atmosphere	Pressure cm Hg column	Volts	Loss in Wt in mg/min	
			anode	cathode
Ar	60	18-20	0,30	1,1
N_2	2	20-26	0,30	1,3
N_2	60	30-34	8,2	14,5
воздух (air)	60	30-34	37,9	17,9

In Table 1 we see that the replacing of air by nitrogen with the same pressure of 60 cm brings about a reduction in the loss of weight in the electrodes, especially of the anode. With the decrease in the pressure of the nitrogen the loss in weight of the electrodes drops, and with a nitrogen pressure of 2 cm in becomes close to the loss in weight of the electrodes in argon. Let us note that besides the arc in the air we always had a greater wear of the cathode than of the anode, which, apparently, is connected with the high density of the current in the cathode spot. In the investigation of arcs between metallic electrodes in a high vacuum [4] it was shown that the pass-

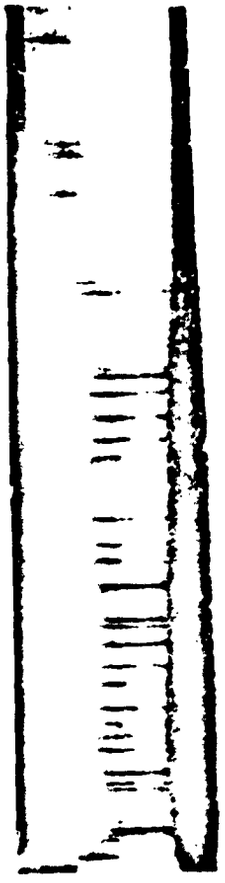

Fig. 5. Spectrum of arc between carbon electrodes in Ar along the discharge.

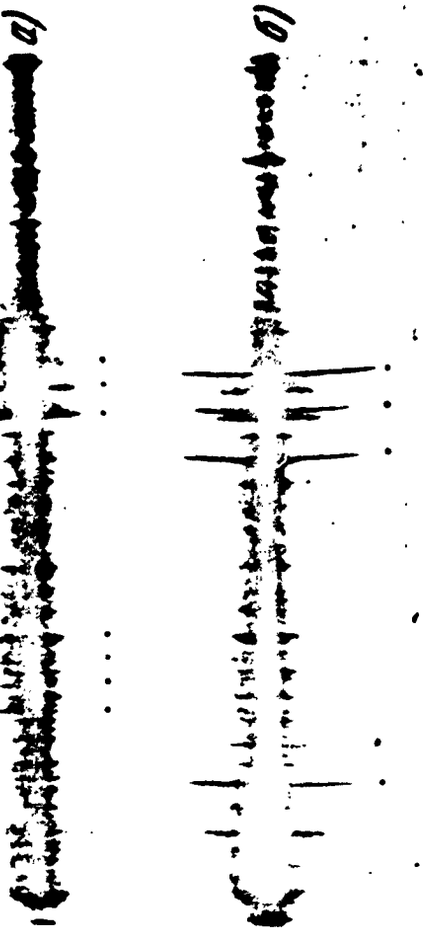

Fig. 6. Spectra of arc between carbon electrodes in Ar across the discharge

Fig. 4. Appearance of discharge

ing of vapors necessary for maintaining the discharge always proceeds from the cathode. The discharge between Fe electrodes in Ar burns more steadily than for 2 cm in N_2 with less fluctuation of V. At 2 cm in N_2 there are

great deviations in the individual measurements of the loss of weight from the average value, presented in the table, sometimes amounting to as much as 50%. With the fluctuations in the passing of vapors one should also connect the convergence of spectra in Ar at 60 cm with the spectra in N_2 in some interval of pressure around 2 cm (0.6—4 cm), which was mentioned above.

Apparently, in the compared discharges there is closeness also of the values of the effective sections of scattering of the electrons by the arc gas $Q_{эф} = q_r N_r + q_M N_M + q_i N_i$. The component $N_i q_i$ takes into account the scattering of the electrons by positive ions. In Table 2 there are presented the Ramsauer effective sections of atoms of Fe, C, and Ar evaluated with the aid of investigations in a strong-current stabilized arc [5, 6] and Ar and N_2 borrowed from the work [7].

The computation $q_r \cdot N_r$ for Ar at 60 cm and N_2 at 2 cm (energies of the electrons $\sim$1 ev) give approximate values $\sim 10^2$ cm^{-1}. The evaluation $q_i N_i$ [8, 5] for $N_e \sim 10^{15}$ and $T \sim 6,000$ — $10,000^\circ$K gives a value of the order of 10^2 — 10^3 cm^{-1}. Consequently, in the evaluation of the effective section of the scattering of the electrons by the arc gas $Q_{эф}$ it is necessary to take into consideration the scattering of electrons by ions, which under these conditions on account of the low $q_r \cdot N_r$ and relatively high N_e has, apparently, basic significance. Short-range entry of easily ionized vapors of metal in an arc in N_2 with lowered pressure and in Ar at 60 cm assures close N_e (r) and consequently also $q_i N_i$.

Table 2

Element	Fe [5]	C, N, O [5]	Ar [6]	Ar [7]	N_2 [7]
$q \cdot 10^{16}$ cm^2	35	20	2.5	2.5 (1 ev)	30—90 (1—2 ev)

In comparing the spectra of the arc between copper electrodes in argon,

air and N_2 at 60 cm with the spectra in N_2 at low pressure we established /114 that the replacing of air by nitrogen and the moreso by Ar at the same pressure changes the appearance of the spectrum. It becomes more sparklike. A still more sparklike character is had by the spectrum of an arc in N_2 at lowered pressure. In Fig. 2 there shown the spectra of a discharge in N_2 at 20 cm, in Ar at 60 cm, and in N_2 at 10 cm Hg column. We see that the spectra in N_2 at 20 cm and in Ar at 60 cm are very similar. The ion and atomic lines in the compared spectra are close as to intensity. However, the line 5,105 Å as to intensity is considerably weaker in the discharge in Ar at 60 cm than in N_2 at 20 cm Hg. column. Besides in the spectrum of Cu in N_2 at 20 cm there are present very intense bands of CN with borders at 3,883, 3,590, and 4,216 Å ($\Delta v = 0, \pm 1$). N_2 with borders at 3,371, 3,159, and 2,977 Å ($\Delta v = 0, 1, 2$), and also NH with borders at 3,360 and 3,370 Å ($\Delta \pm 0$). These bands increase sharply in intensity in discharges with lowered pressure of N_2.

The identification of the bands was done with the aid of the book by Peirce and Haydon [3]. Just the same bands of CN and N_2 were observed by Roes an Smith [9] in a project devoted to a study of the background in the arc between carbon electrodes. Let us note that if one takes the spectrum of the arc between copper electrudes in N_2 at 60 cm immediately after the establishing of the arc up to the stable state, and the electrodes are heated to the temperature corresponding to this state, then it turns out that the spectrum of Cu has a more sparklike character than ordinarily at 60 cm and is very similar to the spectrum of the arc in Ar at 60 cm. All that has been said points to the great effect on the spectrum of of the entry of Cu vapors into the discharge. In Table 3 there are presented data about the entry of Cu vapors in the discharges being compared.

Table 3

Atmosphere	Pressure cm Hg Co	Loss in Weight	
		Anode	Cathode
Ar	60	0,28	1,51
N_2	20	0,25	1,31
N_2	60	3,60	2

From Table 3 we see that in arcs between Cu electrodes in Ar at 60 cm, and in N_2 at 20 cm, which have spectra similar in intensity and character, there occurs also approximate identity of the passing of copper vapors from the electrodes into the discharge. In the literature there are no data about the Ramsauer section of copper atoms. The obtaining of similar spectra in Ar at 60 cm and in N_2 at 20 cm, apparently, should be attributed also to the similar scattering of electrons by ions, possibly also by atoms of Cu if it turns out that Q_{Cu} is great.

In this way, as a result of making the comparison of radiation and wear of the electrodes in a low current arc between metallic electrodes (Fe, Cu) in the air, N_2 and Ar with a pressure of 60 cm, and N_2 with lowered pressure, it is possible to draw the conclusion that the change of an atmosphere of air to N_2, and the more so to Ar, is equivalent to changeover to a discharge with a lowered pressure.

Spectra similar in intensity and character are manifested by arc discharges between metallic electrodes with similar entry of vapors of the electrodes into the discharge, and similar values for the effect sections of scattering of electrons by the arc gas. The effect of the processes of dissociation of molecules of N_2 in arcs in N_2 between metallic electrodes did not appear. This one can explain by the fact that the temperatures are insufficient for the development of these processes, since into the discharge there passes, apparently, a sufficient amount of easily ionized atoms of metals even at lowered pressure, but the energy of the dissociation D of molecules

of N_2 is great (9,764 ev [10]). In the discharge between copper electrodes at lowered pressure the intense molecular spectrum of NH and CN indicates the presence in the discharge of NH and CN. In this discharge some effect may be had by the process of dissociation of molecules of NH (D = 3,42 ev [10], which leads to a less pronounced drop in the temperature in the peripheral areas of the discharge. This should appear in a broader zone of illumination of the lines with low energy of excitation in the spectrum--in heightened intensity of the lines with low energy of excitation. In the spectrum of the arc between copper electrodes the intensities of the lines of Cu I 5105, 5782, and 5700 Å (energy of excitation 3.8 ev) are much higher than in the spectrum of the arc in Ar, while the intensity of the remaining atomic lines (energy of excitation above) is comparable.

2. Arc Discharge between Carbon Electrodes

Very characteristic is the external appearance of the arc discharge between carbon electrodes in an atmosphere of Ar (see insert); it is quite different from the external discharge in an atmosphere of air and nitrogen at the same pressure.

In Fig. 4 there are shown photographs of an arc discharge between pure carbon electrodes with a current strength of 9 amp, the distance between the electrodes being 4 mm in an atmosphere of Ar with P = 60 cm Hg column. Around the cathode there is located a cathode layer, which occupies about 1/5 of the arc interval, and afterwards in the direction of the anode there is some weakening of the brightness of the illumination, then again an increase, for some area close to the anode constancy, and finally in the immediate proximity to the anode again a weakening of the brightness of the illumination. The bright cathode layer is always located normal to the surface of the cathode and very much reminds one of the negative illumination of

a glow discharge. The dark area beyond the cathode layer is analogous to the Faraday dark space, and the area of constant brightness of illuminati n to the positive column.

In Fig. 4 b there is shown a photograph of a discharge with a distance between the electrodes of 10 mm. In accordance with the outward appearance of the discharge there is also a spectrum taken along the discharge (Fig. 5). In moving from the cathode (below) to the anode (above) the behaviour of the intensity of the atomic lines of Ar, band C_2, and the constant spectrum is completely analogous to the change in the total illumination along the discharge, fixed in Fig. 4 a. Analogous distribution of the intensity along the arc discharge was observed by Yagozinskiy [11], who investigated the distribution of the intensity of the Balmer lines of hydrogen along an arc discharge in air with lowered pressure ($P < 5$ cm Hg column). The indicated distribution of intensity along the arc discharge contradicts the mechanism assumed in the work of Kolesnikov and Sobolev [12] of the excitation of the spectrum in an arc between carbon electrodes in an atmosphere of argon. In Fig. 3 there is shown a somewhat enlarge spectrum of the cathode area of discharge with a current of 6 amp in the region of 4158--4800 Å obtained by us on the spectograph ISP-51 with a camera UF-84.

In order to explain the behaviour of the separate lines around the cathode in printing the area of the spectrum > 4300 Å the exposure was done to a somewhat lesser extent in order to weaken the solid illumination which increases in intensity in the direction of the long waves. On the photograph there are shown lines of Ar I; the unmarked lines belong to the illumination of Ar II of the edges of the bands of CN. From the spectrum of the cathode area we see that immediately on the surface of the cathode there stand out with great intensity the lines of Ar II and C II, which as one

moves from the cathode sharply drop in intensity. The atomic lines, however, have maximum intensity at some distance from the cathode, approximately identical for all atomic lines (energy of excitation of lines is close to 14.46--14.76 ev).

From what has been said it follows that the character of the illumination in the cathode area of the discharge is analogous to the radiation in the area of the negative illumination of a glow discharge. A comparison of the wear of the carbon electrodes in an arc in the air at different pressures and in Ar at P = 60 cm also points to a greater entrance of vapors of the electrodes in the arc in Ar and in the air with lowered pressure ($P < 2$ cm).

Very interesting is the appearance of the discharge in the transverse direction--the presence of a core surrounded by a narrow dark space and then an illuminating envelope (Fig. 4 a). In visual observation one can easily see the dull-blue core sharply outlined by a dark fringe, surrounded by violet, and finally by a green envelope, while the green envelope is sometimes expressed very weakly. The dull-blue color of the core is brought about is brought about by the illumination of the very bright lines of Ar I located in the region4702--4158 Å of the corresponding transitions from $^3P_{1-10}$ to $^1S_{2-5}$ levels (Paschen's designations). In the violet envelope there occurs basically an illumination of the bands of CN, and in the green the illumination of the bands of C_2.

In Fig. 6 a there is shown a transverse spectrum of the positive column of an arc between pure carbon electrodes in Ar at 60 cm in the region of 6000--4700 Å. In the spectogram above there are noted the brighter lines of Ar I in this region of the spectrum and with dots below there are marked the edges of the bands of C_2 (in this area of the spectrum the lines of Ar I are much weaker than in the area 4702--4158 Å).

The introduction of vapors of metal changes the character of the illumination of the discharge, and this change is all the more marked the larger the quantities of metal that enter into the discharge. The more the metal vapor the weaker the lines of Ar I will be as well as the continuous illumination. As it turned out in the arc between metallic electrodes there are completely lacking the illumination of the lines of Ar I and the continuous spectrum. In Fig. 6 b there is shown the spectrum of an arc between carbon electrodes with a small admixture of copper in the atmosphere of Ar at 60 cm Hg column (the lines of copper are marked below by dots).

As is seen from Fig 6 b the appearance in the spectrum of the lines of copper is accompanied by some weakening of the lines of Ar I, and also of the continuous and molecular spectrum. Let us note that the obtaining of a simultaneous sufficiently intense illumination of Ar I and Cu I is bound up with difficulties. Ordinarily with a sufficiently intense illumination of the lines of Cu there disappear from the spectrum the lines of Ar I and the continuous radiation, since the introduction of vapors of copper lower the temperature of the discharge.

The observed structural distribution of the radiation across the discharge in an arc between carbon electrodes in an atmosphere of Ar, apparently must be attributed to a unique distribution of the temperature of the electrons over the section of the discharge.

From the work accomplished one can draw the general conclusion that the change from an atmosphere of air to one of nitrogen, and more so for argon, is equivalent to transition to a discharge at a lower pressure.

Substitution of atmosphere in a low-current arc discharge is reflected in the radiation of the arc discharge through a change in the entrance of vapors of the electrodes into the discharge, effective sections of scatter-

ing of electrons by the arc gas, and effect of the processes of dissociation (discharge between carbon electrodes in an atmosphere of nitrogen).

L. P. Murav'yeva took part in the work.

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